Mental Resource Demands Prediction as a Key Element for Future Assistant Systems in Military Helicopters

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Abstract. This work presents an approach to enhance knowledge-based assistant systems in the domain of military helicopter missions with the ability to prevent the pilot from being overtaxed. Therefore, an estimation method for residual mental capacity and current subjective workload is proposed. This estimation enables the assistant system to deduce the pilots' specific needs of support. As a result the assistant system shall be enabled to cooperate with the pilot by resource adaptive information exchange. First evaluation experiments of the prototype, conducted in our research helicopter mission simulator, will be described.

Keywords: Task load, subjective workload, mental resources, adaptive automation.

1 Introduction

Today's army helicopter missions are hardly imaginable without the support of Unmanned Aerial Vehicles (UAVs). In order to facilitate the gathering of closed-loop near real-time tactical reconnaissance data, future UAVs will not only be controlled from ground stations, but also guided from aboard a manned air vehicle. The on-board control of UAVs will add a new and broader range of tasks for the cockpit crew – for the commander as well as for the pilot flying. Due to the extra work demands put on the commander, one critical consequence certainly is the reassignment of cockpit tasks from the commander to the pilot flying, which could result in a noticeable increase of subjective workload. This new spectrum of tasks for the pilot flying, mainly in radio-communication, routing during flight and ad-hoc mission re-routing, is comparable to a single pilot environment.

In this context, the MiRA (Military Rotorcraft Associate) knowledge based assistant system for pilot flying has been developed and tested at the UBM. MiRA and other state-of-the-art approaches of knowledge based assistant systems (e.g. CAMA [8], PA [2]) focus on the provision of support functions in certain predetermined situations. However, they usually detect currently occurring violations of flight and mission parameters and use these as triggers to provide support. The assistant system corrects these errors and prevents further consequences. Suchlike reactive assistant system behavior may result in an overload for the pilot, especially if

the system intervenes at a time when the human operator has no more free cognitive resources to adopt the offered support or interact with the system.

To prevent such situations, within this article an enhancement for the MiRA-assistant system is investigated, which shall allow a model based prediction of the human operator's workload and the remaining capacity of his/her mental resources in the current task situation.

2 Model Based Human Resource and Workload Determination

The Institute of Flight Systems of UBM investigates so called MUM-T (manned-unmanned teaming) approaches for military helicopter missions. Due to the expected reassignment of tasks from the commander to the pilot, we offer support to the pilot by knowledge based assistant systems. This enables the pilot to cope with an extended task load spectrum. The requirements of such an assistant system are described below.

To investigate the interactions between pilot, assistant system and the helicopter, the approach of the work system (introduced by [7]) will provide a framework. A work system refers to the components that perform the work process for achieving a given work objective. This consideration of the work system focuses on the physical dimension of the process on the participating entities.

In contrast to recent approaches of assistant systems (e.g. RPA [5]), we claim an Artificial Cognitive Unit (ACU) to assist the pilot as a co-operative automation element. This mode of automation is characterized by the fact that both the pilot and ACU determine and supervise what will happen in the course of the work process and which Operation-Supporting Means (OSMs) will be deployed at what time.

Fig. 1. Assistant system as part of the Operating Force

Figure 1 depicts the first characteristic of such an ACU, being a part of the Operating Force (OF). Hence, not only the human pilot but also the ACU needs to understand the given work objective. Pursuing a common objective is only possible, if the assistant system is able to understand the necessary tasks to be performed. So, task models have to be developed, which incorporate the a-priori knowledge on military transport helicopter missions. An example for task models on military transport missions for aircrafts can be found in [9]. Secondly, we demand the ACU to co-operate with the pilot as an assistant system like it would be the case if there was a

human assistant (see Figure 2). Hence, it takes initiative on its own in order to accomplish a given common work objective.

Swezey & Salas [11] describe desired capabilities of team members to ease interaction for the sake of team performance. The most important capability, pointed out for designing this work system, is that “effective team members typically help other team members who are having difficulty with a task”. Conversely this means, overtaxing of a team member should be avoided.

Fig. 2. Assistant system Co-operating with the human Operator

Veltman and Jansen [12] describe an inverted U-shaped relationship between the subjective workload (coming along with the work demands, i.e. the task load) and the human work performance (see Fig. 3). At a moderate workload level, performance can be increased to a peak plateau (optimal performance). In situations of high workload, the achievable performance decreases again.

Fig. 3. Relationship between task load, workload and performance [12]

For the reasons mentioned above an ACU should be designed to keep the human workload, and therefore the task load on a moderate level, which permits the pilot to achieve best performance. In order to do so, the ACU has to estimate the demand on

human resources. This estimation shall be done taking into consideration the current task situation. A similar approach of workload determination has been worked on in the RPA program [5]. We particularly investigate an approach considering multiple task situations.

Considering human-machine co-operation, an ACU should be able to make use of the OSMs (see figure 4). To prevent the pilot from overtaxing (see Figure 2), we demand the ACU to adapt all dialogs with regard to the remaining resources as well as to the current workload of the pilot. For this purpose, the ACU has to choose appropriate human modalities to push any information to the pilot for fulfilling the goal of resource-oriented information transfer.

Fig. 4. ACU has to choose appropriate modalities in order to transfer information

3 Detailed Concept

The concept described in the following section and shown in Figure 5 is based on Wickens' model of human cognitive abilities in information acquisition, processing and response [13].

In the first step, an ACU designed according to this approach has to capture as many as possible external information relevant to the pilot during a military transport helicopter mission (i.e. the state of the helicopter, the mission objective, the current flight and mission phase as well as environmental conditions).

After aggregation of this data into a comprehensive situational picture, this information can be used to determine the current tasks, the pilot should be executing momentarily and in the near future. For this purpose models of mission-typical task situations have to be developed on the basis of knowledge acquisition experiments. Such task models represent the rule-based normative behavior of the pilot, as it would be in accordance with aviation regulations and flight manuals [9].

To synchronize the assumed tasks with the tasks the pilot is actually executing, human machine interactions such as visual information acquisition (e.g. gazing at moving map) as well as manual interactions shall be analyzed. Therefore, assumptions are made that observing the gazes [3, 10] as well as observing the manual interactions enables the assistant system to draw conclusions on the tasks actually processed by the human operator.

Fig. 5. Concept for estimating remaining human resources / current workload

In a further step the determined actual task(s) shall be associated with the required human resources, by use of eight-dimensional demand vectors [6].

According to Wickens' [13] so called multiple-resource theory, every demand vector symbolizes the demand a single task poses on the human operator expressed in the terms of information acquisition, information processing and response. To explain the demand vector in detail, a sample for the task “navigate to next waypoint” is illustrated below in Figure 6. To accomplish this task, the pilot has to acquire visual spatial information from the map and the outside view, process this information by the use of cognitive-spatial resources whether he is on track and at last he has to decide and execute a manual control interaction.

Task	demand vector							
	perception				cognition		response	
	visual-spatial	visual-verbal	auditiv-spatial	auditiv-verbal	cog.-spatial	cog.-verbal	man. control	verbal
Navigate to next waypoint	1	-	-	-	1	-	1	-

Fig. 6. Demand vector for the sample task “navigation”

In order to improve the sensitivity of successive resource and workload estimation, all ratings of demand vectors shall be classified according to the following task levels.

- sub-conscious tasks (manual control)
- routine tasks (supervisory control)
- tasks requiring planning and problem-solving

This classification shall provide a basis for a modification of each demand vector.

For the estimation of resource utilization, a Visual-Auditory-Cognitive-Psychomotor (VACP) model [1] shall be customized to make it use for the eight-dimensional demand

vectors as input values. This enables the assistant system to determine the remaining resources and can be used to properly select a free resource for interaction with the pilot.

The W/INDEX-model [6, 14] shall be used as a basis for the estimation of the current workload of the pilot. Due to the limitation of W/INDEX-model handling two tasks at once only, the original method of W/INDEX has to be enhanced for multiple task situations. So the modified W/INDEX model has no limitation on the number of tasks to be processed in parallel [4].

The workload estimation enables the assistant system to decide whether a counteraction would be necessary. A simple way of workload reduction can be realized e.g. via a delay of low prioritized interactions with the pilot.

Moreover the resource consumption model provides an estimation, which human mental resource for information acquisition and processing would be the most suitable one for any necessary information transfer through the assistant system in the current situation. For this purpose possible future assistant system initiatives shall be analyzed using the modified W/INDEX model in order to identify human resource conflicts with respect to the present tasks. As a consequence this estimation enables the ACU to charge human resources equally while generating the lowest cost for the pilots' workload.

4 Module Architecture of Laboratory Prototype

To realize the presented concept, the following module structure (see Figure 7) has been sketched and followed through the development of a laboratory prototype.

Fig. 7. Module architecture of resources / workload estimation system

In the first step, the mission is planned and segmented into several flight and mission phases by the mission objective interpreter. Each of these phases represents a set of tasks. These task models have been developed on the basis of structured interviews during knowledge acquisition experiments with German Army helicopter crews. Based on these sections, the flight phase and mission phase interpreters pursue the progress of the mission, which generates a picture of the current situation. Both, the flight phase and mission phase interpreter have been implemented using state transition networks. This enables the ACU to recognize the task situation in order to deduce the pilots' tasks.

In the next step, the tasks assumed by the ACU, are synchronized with the tasks actually being performed by the human operator. This is done by use of gaze tracking (using faceLAB) as well as observing the manual interactions. Manual interactions which are taken into consideration here include page switching activities on the Control and Display Unit (CDU), further system settings (e.g. landing gear), speech input and output, as well as looking at the magnitude of control stick movements.

During structured interviews with the helicopter crews, every single task has been rated concerning its individual resource demands posed on the pilot. Subsequently, these tasks are transferred into the demand vectors within the pilots' resource model.

Due to restrictions of W/INDEX handling two simultaneous tasks only, the implementation of W/INDEX-model has been modified here by the use of pairwise weighting of all current tasks. Starting with the W/INDEX-conflict matrix suggested by Wickens [14], we modified the conflict-coefficients to our needs.

Based on the estimation of conflicts (caused by actual and possible future assistant system tasks) a rating of preferred interaction modality (either visual-ambient, visual-verbal, auditory-verbal or auditory-ambient) has been implemented. If any information transfer is required, this rating is used by the ACU to choose appropriate OSMs for communicating in a resource adaptive way with the pilot.

5 Preliminary Experimental Testing of Resource Model Prototype

A first engineering test in our flight simulator has been conducted in order to investigate the resource adapted interventions of the assistant system using predictions made by the resource model described in the previous sections.

5.1 Experimental Procedure

In this test, the interventions made by the ACU are of the types "associative assistance" and "alerting assistance" [7]. The purpose of "associative assistance" is to offer its proposals (e.g. "next turn heading") continuously to the pilot such as a commander would do this. In contrast "alerting assistance" assumes to fulfill a kind of artificial cognitive redundancy, which is only intervening in situations, the pilot does not seem to be completely aware of. Here the attention of the pilot is drawn on the most urgent task, e.g. by presenting appropriate hints.

Both, "associative assistance" as well as "alerting assistance" serve to fulfill the goals of cooperation.

Particular emphasis has been put on the selection of the perceptual modality, the ACU chooses in order to interact with the pilot. According to our concept the following hypotheses should be evaluated within the experiment:

- The human operators' remaining resources are dependent on the current task situation.
- Based on the estimated resource consumption, the ACU as assistant system interacts on residual human resources in order to charge these resources equally.

5.2 Mission Configuration

In our scenario, a manned military transport helicopter carries troops from a pickup zone in friendly area to an operation area at foe with two possible drop zones nearby. The commander controls three UAVs, which are flying ahead of the manned helicopter taking over reconnaissance.

Due to this additional UAV-guidance, the pilot is required take over tasks, otherwise typically executed by the commander. These delegated tasks mainly count among mission-management (e.g. radio communication) and routing of manned helicopter during flight.

5.3 Simulation Environment

The mental resource demand predicting prototype has been implemented on a generic two-man side-by-side helicopter simulator, used for research-projects at the Institute of Flight Systems. This simulator consists of six multi-function displays (MFDs), each attached with a touch screen. Depending on the configuration, display formats such as a Primary Flight Display (PFD), a digital map, system status or a radar warning system can be shown. Complex (mission specific) information e.g. communication radio frequency and transponder settings have to be entered into a Control and Display Unit (CDU). For the simulation of the external environment, a three-channel projection system with a viewing angle of 180° was built up. The pilot in command on the left side takes the additional tasks as operator of UAVs.

5.4 Results

In Figure 8, the results of human resource prediction are shown in the context of ACU-interventions. Line 1 to 8 depicts the prediction of resource-consumption, based on the modified VACP. In Line 9, the workload level, estimated by the modified W/INDEX is drawn.

During the flight in friendly area (up to 500sec), the estimated workload was mostly low with only little peaks. The first intervention of the ACU, classified as “associative assistance”, used the visual-verbal channel (VV) to transfer its information to the pilot by generating a text message on display. This modality has been chosen because of allocated demand on the audio-verbal-channel (AV) through a concurrent radio message.

After entering the enemy area (past 600sec) the ACU intervenes by using “alerting assistance” due to the fact, the pilot impends to violate a safety critical aircraft altitude. But by aid of resource adapted interactions, the ACU-induced (not avertable) increase of estimated workload is marginal.

Particularly high resource consumption and workload estimation was observed around 800sec. This correlates with the reconnaissance of enemy jeeps near the desired landing area. In this context, the pilot was working on the rescheduling of the drop zone.

Fig. 8. Experimental results of implemented resource consumption model

6 Conclusions and Perspective

In this article, an approach is presented to enhance cooperative capabilities of future knowledge-based assistant system in the domain of military helicopter missions. For this purpose, we developed a concept for the estimation of pilots' residual capacity in human resources as well as an estimation of his current workload level. By the use of models considering the current resource allocation, an assistant system will be enabled to transfer necessary information on remaining resources of the pilot. This will prevent the pilot from being overtaxed proactively which maximizes the performance of overall system.

The future work will incorporate a validation and verification of the underlying models, especially the task model as well as the resource model, within extensive simulator trails.

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